

Harvest yields of greenhouse tomatoes grown in pine bark amended cotton gin compost

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Abstract

Tomatoes are the most abundantly produced greenhouse vegetable crop in the United States. The use of composted substrates has increased in recent years for the greenhouse production of many vegetables, bedding plants, and nursery crops. 'Blitz' tomatoes were grown during the spring and fall growing seasons in six substrate blends of pine bark (PB), a traditional production substrate in the southeastern US, and cotton gin compost (CGC), an agricultural by-product, to assess the potential use of CGC as a viable replacement for PB for the production of greenhouse tomatoes. Treatments ranged from 100% PB to 100% CGC. Plants grown in substrates containing CGC produced similar total yields during both seasons compared to plants grown in 100% PB. In both seasons marketable yields were similar across all treatments. Similarly, cull fruit was not different across treatments. Substrates containing 60% or more CGC had significantly higher electrical conductivity (salt) levels both initially and throughout both growing seasons than did 20 and 40% CGC and 100% PB substrates. Water holding capacity increased as the percent CGC increased in each substrate, indicating the need for adjusted irrigation volume for substrates containing CGC compared to the 100% PB. Results indicate that CGC has potential to be used as an amendment to PB in greenhouse tomato production.

Keywords: alternative substrates, composting, greenhouse tomatoes

INTRODUCTION

Increased demand for tomatoes (*Solanum lycopersicum* L.) for fresh consumption and export has facilitated the need for large scale greenhouse production. Due to the high cost of greenhouse tomato production, evaluating the potential of lower cost substrates for production could help offset rising costs for fuel, labor, etc. in greenhouse tomato production. Many types of organic substrates are currently available for the production of greenhouse tomatoes including peat moss, perlite, rock wool aggregate, glass wool, pine bark, sawdust, and several others (Papadopoulos and Ormrod, 1990; Snyder, 1998). Pine bark (PB) is the most commonly used substrate for greenhouse tomato production in Alabama and much of the southeastern United States due to its relative low cost and widespread availability (Snyder, 1998). More recently, composted organic materials have been utilized for both ornamental and greenhouse vegetable crop production. Tomato plants grown in wood fiber were shown to have no significant shoot or root growth differences compared to plants grown in a traditional peat substrate (Gruda and Schnitzler, 2004). Composts produced from mixtures of sewage sludge, vermicompost, biosolids, and plant residues such as rice hulls and yard waste have shown potential as alternative substrates for greenhouse tomato production with equal or increased shoot and root dry matter compared to tomatoes grown in a 67% sand and 33% soil substrate (Hashemimajd et al., 2004).

Each year, the US cotton industry harvests 17 to 18 million bales of cotton that go through the ginning process to separate the lint and seed from the cotton gin trash (CGT) (Fava, 2004). CGT is the term used to describe the by-products of the cotton ginning process that consist mainly of reproductive and vegetative parts of the cotton plant that were collected during harvest (Buser, 2001). It is estimated that 1.2 to 2.5 million metric tons of cotton gin

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by-products other than cottonseed are produced annually by US cotton gins, creating a significant disposal problem to the ginning industry (Buser, 2001). One use of CGT requires the materials to be composted to produce cotton gin compost (CGC). CGC has been studied with positive results suggesting its use as a potential substrate component for the production of horticultural crops (Papafotiou et al., 2001; Jackson et al., 2005a, b). With limited information available demonstrating the successful use of organic composted materials as substrates in greenhouse tomato production, there are no generally accepted recommendations or guidelines for their utilization (Rippy et al., 2004). Specifically, there is a need to determine if CGC can be utilized as an amendment to PB for greenhouse tomato production. The objective of this study was to evaluate CGC as an amendment to PB for the greenhouse production of tomatoes.

MATERIALS AND METHODS

Experiments were conducted in the spring and fall 2004. Methodology for both seasons was the same except where noted. Cotton gin waste was obtained from the Milstead Farm Group, Inc., Shorter, AL, and windrow composted for six months at the E.V. Smith Research Center, Shorter, AL. In January 2004, the CGC was collected and sifted through a 15-mm screen to remove foreign debris, rocks, and clods in preparation for the spring experiment. Six substrate blends of aged and milled PB and CGC were mixed (by vol) in the following ratios 100:0, 80:20, 60:40, 40:60, 20:80, and 0:100. Thus, treatments contained 0, 20, 40, 60, 80, or 100% CGC. This procedure was repeated in August 2004 to mix substrates for the fall season of this study, with CGC being used from the same batch obtained in January 2004 which had been dry-stored. Based on initial pH values determined from three representative samples of each substrate blend, varying amounts of dolomitic limestone were added as follows to achieve a pH near 6.2: 100:0 PB:CGC received 1.5 kg m⁻³, 80:20 PB:CGC received 1.3 kg m⁻³, 60:40 PB:CGC received 0.9 kg m⁻³, 40:60 PB:CGC received 0.7 kg m⁻³, 20:80 PB:CGC received 0.4 kg m⁻³, and 0:100 PB:CGC received 0.4 kg m⁻³.

Plants in each season were arranged in a randomized complete block design (RCBD) with three plants (sub-plots) of each treatment within each of four blocks. Blocks were oriented North to South in a greenhouse bay measuring 10.1×9.1 m (91.9 m²) at the Plant Science Research Center at Auburn University, Auburn, AL. The greenhouse was equipped with a Modine high efficiency gas heater and an evaporative pad system for cooling. Maximum daytime temperature was set at 27°C and minimum night temperature was 18°C. Seeds of 'Blitz' tomato (*Lycopersicon esculentum* Mill.) (Paramount Seeds, Inc. Palm City, FL.) were planted in 36-count cell flats (4×7.5×5.5 cm) containing Premiere Pro-Mix BX (Premier Horticulture Ltd., Dorval, Quebec). Tomatoes for the spring study were seeded on December 16, 2003 and were grown for seven weeks under natural light conditions on greenhouse benches. Tomatoes for the fall study were seeded on July 13, 2004 and grown for seven weeks at the same location under natural light. In each study, seedlings were irrigated twice daily and fertilized once weekly with 15N-7P-14K (Scotts Co., Marysville, OH) at the rate of 100 ppm N. Seedlings were transplanted on February 2, 2004 (spring), and on August 17, 2004 (fall). One seedling was transplanted into each 10-L Bato Hydro Bucket (Bato Trading B.V., Zevenbergen, The Netherlands) pre-filled with substrate. Prior to filling, a 3.2-cm hole was drilled in the bottom of each container to facilitate adequate drainage when irrigated. Each hole was covered with a double layer of mesh screen to prevent loss of substrate from the container. Once filled with substrate, each Bato container was placed on a single layer of cinder blocks (block dimensions: 19×19×39 cm) to elevate the containers above the greenhouse floor so that leachate could be collected from beneath.

Once transplanted, plants were fertigated in six cycles daily using 1.9 L h⁻¹ drip emitters. One emitter was placed in each of the four corners of the containers to ensure uniform moisture distribution. Plants were fertigated automatically by a MC-8 Plus Irritrol Irrigation Controller (Irritrol Systems, Riverside, CA) at 0700, 0900, 1100, 1300, 1500, and 1700 h. Nitrogen (N) concentration of the fertilizer solution for each stage of plant growth and fruit development were as follows: Stage 1, transplanting to anthesis of flowers on first cluster, plants received 71 ppm N; Stage 2, first cluster fruit set to second flower cluster anthesis,

plants received 81 ppm N; Stage 3, second cluster fruit set to third flower cluster anthesis, plants received 101 ppm N; Stage 4, third cluster fruit set to the fifth flower cluster anthesis, plants received 154 ppm N; and Stage 5, fifth cluster fruit set until termination, plants received 175 ppm N. Fertilizers were tank mixed weekly and stored separately in 114-L containers. Tensiometers (Model LT; Irrrometer Company, Inc., Riverside, CA) were placed into one container of each treatment, in each block, at each end of the greenhouse (a total of two for each treatment) to monitor soil moisture levels for each treatment. Irrigation volume for each treatment over the course of the spring and fall crops was modified as needed in conjunction with plant growth, daily weather conditions, and tensiometer readings. Maintaining consistent substrate moisture levels within all treatments, initially 100% PB and 20% CGC substrates received 1.7 L plant⁻¹ daily, 40 and 60% CGC substrates received 1.44 L plant⁻¹ daily, while 80 and 100% CGC substrates received 1.2 L plant⁻¹ daily.

Plants were strung when they reached approximately 0.7 m in height using twine suspended from overhead support wires. As the plants grew, the twine was periodically wrapped around the stem, and vine clips were added for additional support. Axillary suckers were removed as needed when they reached roughly 7.6 cm in length. Manual pollination was completed every other day during the flowering period by vibrating the flower clusters with an electric toothbrush. Pollination was performed between 11:00 and 14:00 h as recommended by Snyder (1998). In both seasons, fruit clusters were pruned to four to five evenly sized fruit per cluster. Truss (inflorescence) string clips were attached to each fruit cluster to provide stability and support to the enlarging fruit. Plants in the spring study were grown until seven fruit clusters had developed, at which time each plant was topped by removing the terminal bud of the main stem. Plants in the fall study were grown until each plant produced five fruit clusters before the terminal bud was removed. Each crop was terminated after all fruit had matured and were harvested. The spring crop was terminated on June 10, 2004 and the fall crop on December 3, 2004.

Tomatoes were harvested weekly at the light red stage of fruit maturity where 60 to 90% of the skin surface was red in color (USDA, 1997). Marketable fruit were >58 mm in size and free from visible defects including irregular shape, growth cracks, blossom scars, blossom end rot, and zippering (USDA, 1997; Snyder, 1998). Within marketable fruit, the following grades were determined based on the size of harvested tomatoes: medium 58-63 mm; large 64-72 mm; extra-large 73-88 mm; and jumbo >88 mm. Fruit with defects plus fruit <58 mm were classified as culls. Total yield for each season was the sum of total marketable yield plus total cull yield.

Physical properties including air space (AS), water holding capacity (WHC), total porosity (TP), and bulk density (BD) were determined for each substrate using the North Carolina State University Porometer method (Fonteno et al., 1981). Leachate pH and electrical conductivity (EC) were measured at experiment initiation and periodically throughout each growing season using a hand-held Myron DS/pDS meter (Model EP-11; Myron L Company, Carlsbad, CA).

Data were analyzed for each study using GLM procedures (SAS Institute, Inc., 2004). Regression analysis was performed to describe effect of treatment on yield (total and marketable) within early, mid, and late season harvests. Means separation (LSD) was used to determine differences among treatments for leachate EC and percentages of marketable and cull yield for each study. Initially, data from the spring and fall studies were pooled and analyzed. Analysis of variance (ANOVA) indicated a significant ($P \leq 0.001$) season \times harvest date interaction (data not shown). This indicated that the effect of treatments on yield differed in the spring and fall and as a result data from the spring and fall were analyzed separately.

RESULTS AND DISCUSSION

Total yield

The effect of treatment on average total yield per plant was similar across all treatments in the spring study and ranged between 2.3 and 2.6 kg plant⁻¹. In the fall study treatments containing 40, 60, and 80% CGC had significantly higher average total yields plant⁻¹ ($p \leq 0.05$)



which ranged between 1.2 and 1.3 kg, than that of the 100% PB treatment which averaged 0.9 kg total yield plant⁻¹ (p≤0.05). There was no statistical difference between 100% PB and 100% CGC treatments in the fall study. These results were similar to previous work described by Madrid et al. (1998) and Reis et al. (2001) who reported higher or similar total fruit yields of greenhouse tomatoes when grown in compost or compost amended substrates.

Marketable yield

Average marketable fruit yield plant⁻¹ in the fall was higher in treatments containing 40% (1123.7 g plant⁻¹), 60% (1182.5 g plant⁻¹), and 80% (1154.8 g plant⁻¹) CGC than in 100% PB control (896.6 g plant⁻¹) (p≤0.05) (Table 1). While in the spring study, average marketable yields plant⁻¹ were similar across all treatments ranging from 2092.9 to 2260.8 g plant⁻¹ with an average of 2149.6 g plant⁻¹ (p≤0.05) (Table 1). Within each of the marketable fruit grades, treatment effects were similar in both the fall and spring (Table 2). The percentage contribution to total fruit yield by marketable fruit was similar among all treatments in the spring and fall.

Table 1. Average marketable and cull fruit yield in grams per plant for greenhouse tomatoes container-grown in six pine bark (PB):cotton gin compost (CGC) substrate blends for two growing seasons in 2004^a.

PB:CGC	Total marketable ^b		Total cull ^c	
	Spring	Fall	Spring	Fall
100:0	2161.0a ^d	896.6c	204.0a	56.2a
80:20	2054.1a	939.9bc	259.3a	56.2a
60:40	2157.8a	1123.7ab	281.9a	64.6a
40:60	2260.8a	1182.5a	360.5a	78.6a
20:80	2168.4a	1154.8ab	356.7a	67.8a
0:100	2092.9a	1000.4abc	291.8a	70.1a

^aStudy conducted in a climate controlled greenhouse with maximum day temperatures of 27°C, and minimum night temperatures of 18°C.

^bMarketable fruit: Jumbo = fruit >88 mm in size; X-Large = fruit between 73 and 88 mm in size; Large = fruit between 64 and 72 mm in size; and Medium = fruit between 58 and 63 mm in size (USDA, 1997). All fruit were also free from visible defects.

^cCull fruit: too small (<58 mm in diameter); irregular shape; scars; growth cracks; blossom-end rot; zippered.

^dMeans within a column followed by the same letter are not significantly different according to Fisher's Protected LSD at P=0.05.

Table 2. Yield of grades of marketable greenhouse tomato fruit in grams per plant when container grown in six pine bark (PB):cotton gin compost (CGC) substrate blends for two growing seasons in 2004.

PB:CGC	Jumbo ^a		X-Large ^a		Large ^a		Medium ^a	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
100:0	434.0bc ^b	18.0b	1326.4a	422.2c	380.7a	396.2a	20.0ab	60.3a
80:20	382.7c	34.2b	1225.4a	578.1bc	418.2a	280.0ab	27.9a	47.7ab
60:40	539.4abc	78.0ab	1271.0a	740.4ab	322.7a	284.4ab	24.7a	20.9b
40:60	642.9ab	112.2a	1425.2a	822.0a	183.9bc	231.3b	8.8ab	17.1b
20:80	729.2a	78.4ab	1231.5a	800.0a	205.1bc	230.0b	2.7b	46.4ab
0:100	636.0abc	68.7ab	1290.8a	653.8ab	157.9c	237.5b	8.3ab	40.3ab

^aJumbo = fruit >88 mm in diameter; X-Large = fruit between 73 and 88 mm in diameter; Large = fruit between 64 and 72 mm in diameter; and Medium = fruit between 58 and 63 mm in diameter (USDA, 1997). All fruit were also free from visible defects.

^bMeans within a column followed by the same letter are not significantly different according to Fisher's Protected LSD at P=0.05.

Culls

In both studies yields of fruit with growth cracks, rough blossom scars, or irregular shapes were not different among treatments (Table 1). Yield of fruit with growth cracks ranged between 77 and 158 g plant⁻¹ in the spring and between 32 and 52 g plant⁻¹ in the fall. Yield of fruit with rough blossom scars ranged between 16 and 56 g plant⁻¹ in the spring and between 0 and 4 g plant⁻¹ in the fall. Yield of irregular shaped fruit ranged between 46 and 112 g plant⁻¹ in the spring and between 0 and 18 g plant⁻¹ in the fall. Amount of fruit with zippering, blossom-end rot, or those that were too small, were similar among all treatments in the fall, but showed slight treatment differences in the spring in all substrates. The percentage that culls represented to the total fruit yield was similar among all treatments and ranged from 8 to 14% in the spring and 4 to 9% fall.

Chemical properties

Leachate pH remained consistent in all treatments through the duration of the spring and fall remaining between 6.3 and 6.7. EC values measured initially and throughout both studies were higher in all substrates containing CGC (Table 3) which is likely due to the high initial EC levels. EC levels decreased in the final measurements in treatments containing above 60% CGC, but levels increased in 100% PB and in 20 and 40% CGC treatments (Table 3). This decrease in final EC levels in CGC treatments above 40% could potentially be due to leaching of the substrates over the duration of the study or by uptake of available nutrients by the quickly developing plants. In contrast, PB as a substrate has very low initial EC levels so the 100% PB and the 20 and 40% CGC treatments were lower initially, but increased over the duration of the study due to fertigation. Despite high EC levels in substrates containing more than 60% CGC, no adverse effects were shown on tomato plants or on the overall total yield. Weekly flushing of the substrates with tap water could explain the absence of salt burn or foliage symptoms in spite of high EC levels. High initial EC levels and consistent pH values over 6.0 were similar to other research reported by Pill and Ridley (1998) who evaluated the response of greenhouse tomatoes when grown in a coir dust soilless media.

Table 3. Average of initial EC from three greenhouse tomato sub-plots grown in six pine bark (PB):cotton gin compost (CGC) substrates during two growing seasons in 2004.

PB:CGC ratio	Spring EC (mmhos cm ⁻¹)		Fall EC (mmhos cm ⁻¹)	
	Initial	Final	Initial	Final
100:0	0.3e ^a	1.9e	0.3e	1.9d
80:20	0.7e	2.9d	0.7de	1.9d
60:40	2.0d	3.5d	1.4cd	2.9c
40:60	4.9c	4.2c	2.1c	3.4bc
20:80	6.9b	6.1a	5.9b	4.5a
0:100	9.8a	5.2b	8.6a	4.2ab

^aMeans within a column followed by the same letter are not significantly different according to Fisher's protected LSD at $P=0.05$.

Physical properties

Water holding capacity was significantly higher in all treatments containing CGC (ranging from 62.4 to 72.5%) than in the 100% PB control (53.2%; Table 4). Tensiometer readings taken from each treatment allowed irrigation to be adjusted to maintain consistent moisture among treatments throughout the study to compensate for the much lower WHC of the 100% PB substrate. The ability of the CGC to hold more water could reduce the irrigation volume needed in greenhouse tomato production, a potentially significant benefit for large scale greenhouse growers. Air space was higher in 100% PB than in any CGC amended treatment (Table 4), due to its larger particle size thereby having a greater number of macropores. Total porosity and BD was lowest in 100% PB and increased significantly as the percent CGC increased in each treatment (Table 4). Higher TP and BD can be attributed to the finer particle size of CGC. The differences in physical properties had no apparent effect on

tomato yield.

Table 4. Physical properties of six pine park (PB):cotton gin compost (CGC) substrates.

PB:CGC ratio	Water holding capacity ^a (%)	Air space (%)	Total porosity (%)	Bulk density (g cm ⁻³)
100:0	53.2d ^b	18.5a	71.7d	0.20c
80:20	62.4c	9.6c	72.0d	0.21c
60:40	67.9b	8.4cd	76.2c	0.21c
40:60	69.6ab	7.6cd	77.2c	0.24b
20:80	72.5a	6.9d	79.4b	0.25ab
0:100	69.1ab	12.4b	81.5a	0.27a

^aValues are based on percent volume of the substrate and were measured at container capacity (Fonteno et al., 1981).

^bMeans within a column followed by the same letter are not significantly different according to Fisher's Protected LSD at $P=0.05$.

CONCLUSIONS

Based on the results of our study, all PB:CGC blends tested appeared suitable for greenhouse tomato production. Foliar tissue analysis results indicated that plants acquired essential plant nutrients similarly regardless of the substrate in which they were grown, and produced similar total and marketable yields regardless of the initial nutritional content of the substrates. Treatments having no effect on fruit yield or overall grade differences signify that no adverse effects should be expected from incorporating CGC with PB into a production system. Evidence in these studies suggest CGC can be used as an amendment to, or as a replacement for PB, with yields and plant composition similar to that achieved with the traditional PB substrate.

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